

A COMMERCIAL HYDROGEN MASER, PROGRESS REPORT

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ABSTRACT

Efratom Systems Corporation has been participating in an NBS Industrial Research Associate Program since July, 1981. One of the goals of this program is to produce new and improved small passive hydrogen masers. Efratom will then develop a commercially available full production hydrogen maser.

This paper describes the design of the new small passive hydrogen maser prototype and some anticipated design changes between the version reported in this paper and the commercial versions.

Specifications of the commercial hydrogen maser and performance data of the prototype are given.

INTRODUCTION

This paper describes a program that has been in progress for about a year and a half to design, build and test a Compact Passive Hydrogen Maser atomic frequency standard, in a form suitable for quantity production, with the goal of making this instrument widely available in the commercial market place. The design is derived from the extensive technology in passive hydrogen masers, evolved over the past five years at the National Bureau of Standard by Dr. Fred Walls and his co-workers.

Efratom Systems Corporation has entered into the Industrial Research Program with NBS to effect the transition of the laboratory accomplishments to the level of a practical and economically producible system. It is a major objective of this program to achieve small size and high reliability, while preserving the extraordinary performance already demonstrated by the NBS passive maser.

System design

Figure 1 shows the overall compact hydrogen maser block diagram. The description of operation of the passive hydrogen has been presented in previous NBS publications [1,2,3,4], therefore only the changes in the new design will be described.

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Physics package

The primary change in the physics package (see figure 2) is the use of a quadrupole magnet as the state selector. (The old design uses a hexapole magnet.) The use of a quadrupole has two advantages. First, it permits a reduction in the length of the physics package from 36 to 19.5 inches. Second, it increases the efficiency of state selection thereby allowing a reduction in the flux of molecular hydrogen required to achieve an acceptable signal to noise. The use of a quadrupole should allow at least a factor of two reduction in the present H₂ consumption rate. This latter advantage of the quadrupole is extremely important because it has a very beneficial impact on the requirements for the maser vacuum system and H₂ storage, allowing a significant decrease in the overall size and weight of the maser without sacrificing reliability.

Frequency synthesizer

A new synthesizer was designed for the maser to provide finer output frequency adjustment resolution than was available with the commercial synthesizer used in the old design. The new synthesizer can adjust the output 5.0 MHz in 2×10^{-14} steps over a range of $\pm 2 \times 10^{-11}$

Two synthesizers have been built, and spectral purity and output isolation measurements were made with the following results:

L(f)@ 5 MHz	-116 dB @ 1 Hz
	-140 dB @ 10 Hz
	-160 dB @ 100 Hz
Isolation (Output to Output)	119 dB

Dissociator

Three dissociator cell sizes were tried, and it was found that a smaller cell is generally more efficient. Also, if RF power is scaled in accordance with cell size, there is some indication that a small cell may be more reliable.

As a result of these studies a cell size of 19 mm O. D. by 46 mm long was chosen. Once fabricated, the pyrex cell is annealed for approximately eight hours with hydrogen flowing through it.

The dissociator electronics is a single transistor self-excited oscillator, based on the design used in EFRATOM's rubidium oscillator. High electric fields are present before the discharge is ignited; these fields are sufficient to ignite the discharge. Once lit, the field intensity is substantially reduced and coupling to the plasma is evenly distributed over the cell surface. The nominal D.C. operating power of this circuitry is about 2.0 watts. This low power dissipation has several advantages:

- 1) No active cooling is required
- 2) Only about a third of this power (.7 watts) is dissipated in the bulb, thereby keeping the temperature rise low, which should help increase life
- 3) The relatively low energy plasma will keep deterioration of the bulb's inside wall to a minimum, thereby increasing life

Dissociation efficiency was measured comparing input power to atom flux for various dissociator configurations. Measurements of atom flux were performed using a kapton-platinum recombination detector in a balanced bridge. Some test results are shown in figure 4. For further information see [5].

Performance Data

Figures 3, 5 and 6 show data taken at NBS on the NBS small passive hydrogen maser. The primary differences between the NBS maser and the new commercial maser (CPHM) are:

- 1) CPHM has a new microwave amplifier that improves noise figure by about 3.5 dB. This should improve short term performance by a factor of about .67.
- 2) CPHM has the new frequency synthesizer
- 3) CPHM uses a quadrupole state selector with shorter beam optics
- 4) CPHM has a new hydrogen pressure servo loop which will directly servo hydrogen atom density in the storage bulb
- 5) CPHM has magnetic shielding around the source end to reduce the maser sensitivity to changes in ambient magnetic field

Figure 3 shows Allan variance data that was obtained by comparing the NBS passive hydrogen maser against three other clocks. The clocks were NBS-4 (a stable laboratory cesium standard) and the two best commercial cesium clocks in the NBS ensemble. Three-cornered hat analysis was performed on three sets of clocks, each set having the maser as one member. The RMS of this data is shown in figure 3.

It should be noted that frequency drift is not removed from the data. Also other measurements of the maser versus the NBS ensemble have not shown a flicker floor for the maser, with data that extends out to thirty-two days.

Figure 5 is a plot of the fractional frequency deviation of the NBS passive maser versus NBS-4 for one day averages. Only an average frequency offset is removed from the data. A linear least squares curve fit to the data shows a drift of about 1×10^{-16} /day. (Note: the reported accuracy of NBS-6, the primary frequency standard, implies an ability to measure absolute frequency drift of 3×10^{-16} /day for long data sets. Given this limit, we have not been able to find a measurable drift in the maser for data runs up to 72 days in length.)

Figure 6 is a plot of the time difference between the maser and NBS-4. Again, only an average offset frequency has been removed. The peak-to-peak deviation for the pair is 10 ns over 38 days.

Figures 7 and 8 are the preliminary specifications for the commercial hydrogen maser. Some of the specifications are derived from data obtained on the NBS small passive hydrogen maser. The specifications will be updated when more data become available on the CPHM, and the device is more fully characterized.

Acknowledgements

We would like to thank all the people in the Time and Frequency Division at NBS for their help. We are especially grateful to Dr. Fred Walls for his help in all areas of maser technology, Dave Howe for his help on the microwave cavity, Dave Allan and Jim Barnes for their help on data analysis, and Dr. Karl Persson for his work on the dissociator.

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CPHM BLOCK DIAGRAM

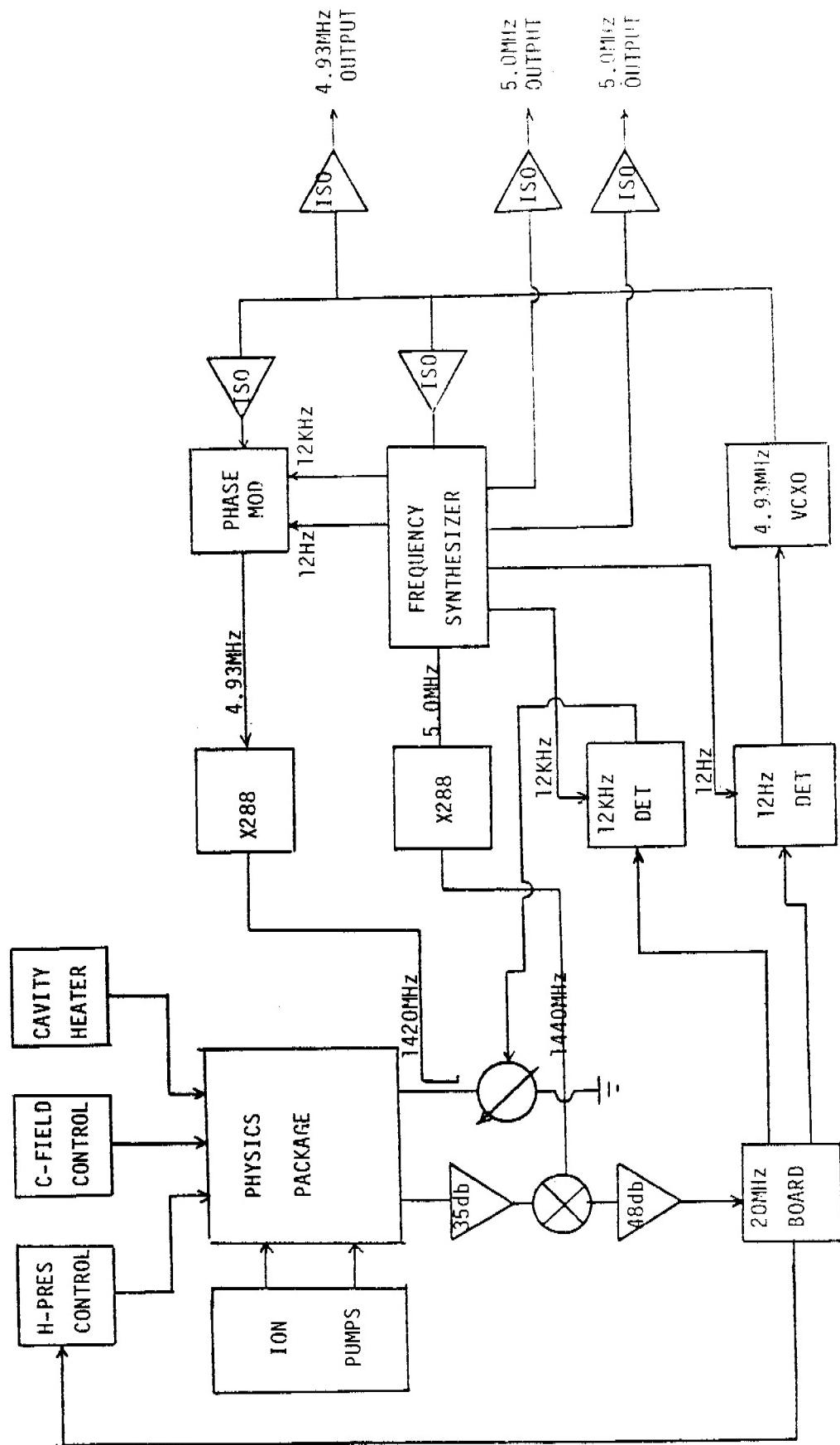


FIGURE 1

PHYSICS PACKAGE

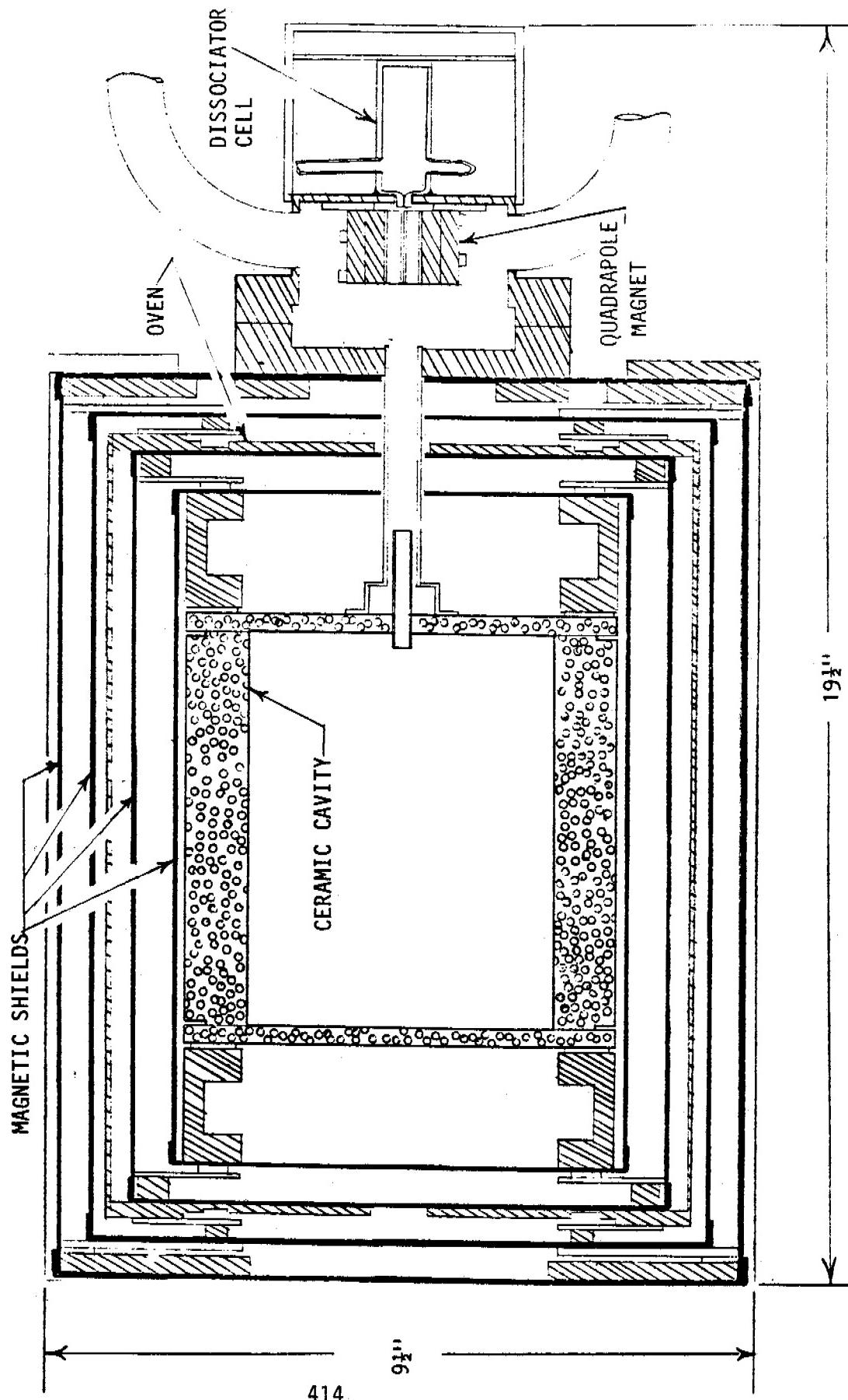


FIGURE 2

PASSIVE HYDROGEN MASER STABILITY

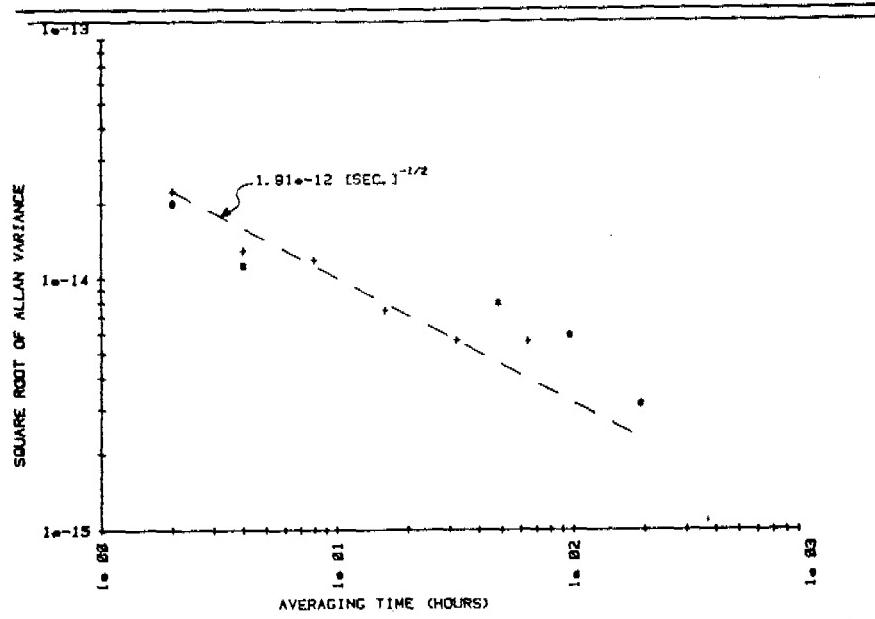


FIGURE 3

DISSOCIATOR PERFORMANCE

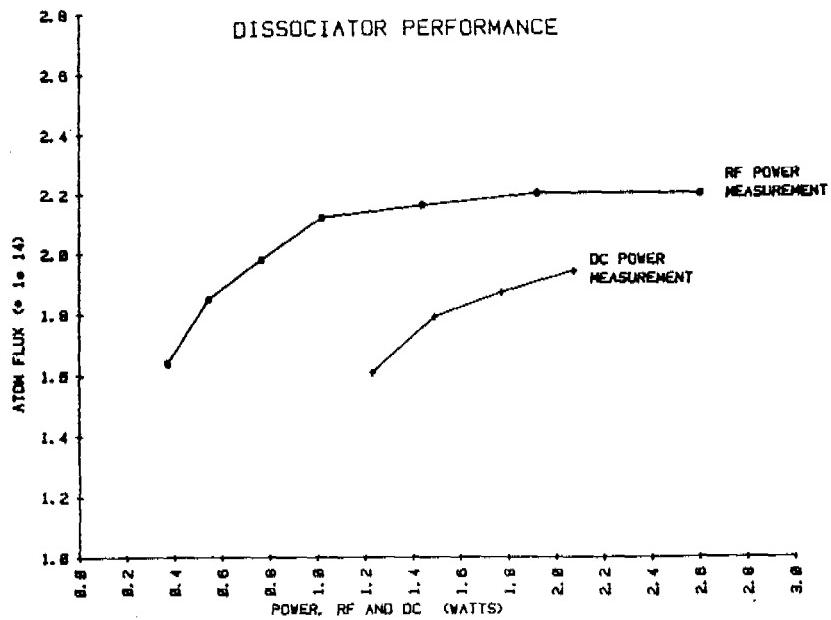


FIGURE 4

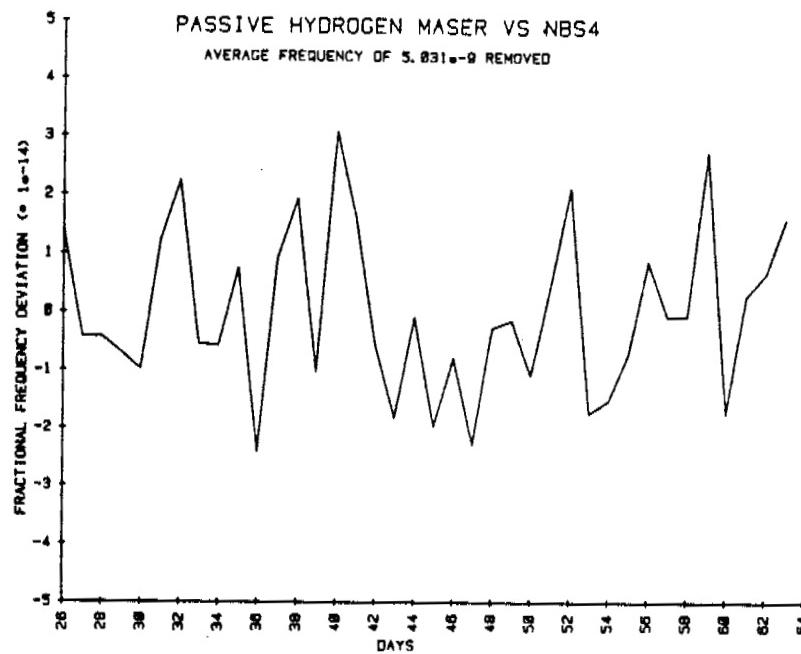


FIGURE 5

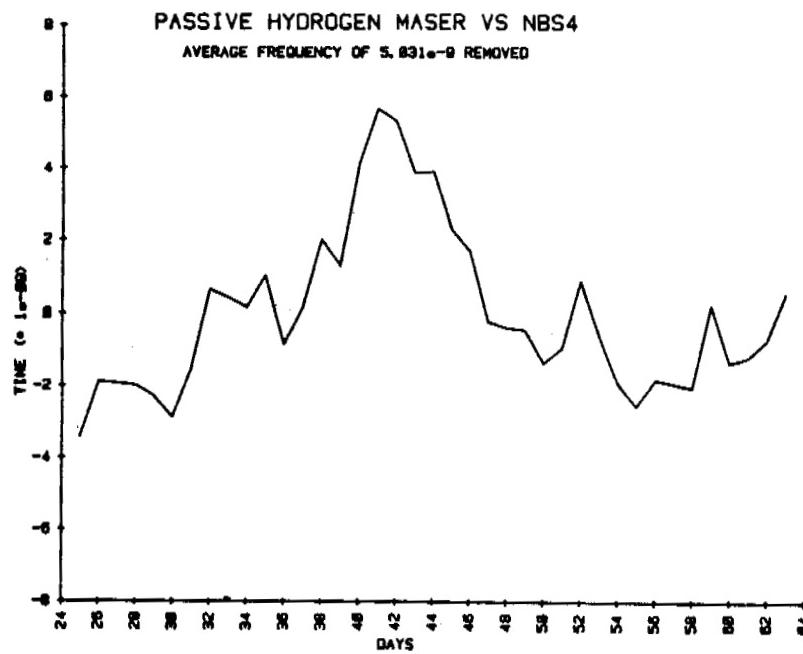


FIGURE 6

Specifications

PASSIVE HYDROGEN MASER PRELIMINARY SPECIFICATIONS

Output	5.0 MHz Sine wave, 1 Vrms, 50Ω, 2 buffered outputs
Isolation(Output to Output)	>110 dB
Signal-to-Noise Ratio	-113 dB at 1 Hz
L(f) at 5 MHz	-135 dB at 10 Hz -155 dB at ≥100 Hz
Short-Term Stability	$\delta f = 2 \times 10^{-12} \tau^{-\frac{1}{2}}$ for 1s < τ < 10,000s
Long Term Drift	<1x10 ⁻¹⁵ /day (Note 1)
Max. Frequency Change Over Life of Unit	<±1x10 ⁻¹²
Retrace (Turn Off, Turn On)	<5x10 ⁻¹³
Temperature Coefficient	<5x10 ⁻¹⁴ /°C
Magnetic Field Sensitivity	1x10 ⁻¹³ Δf/f for Δ ext. field of ±1 gauss (Note 2)
Input Power (Steady State)	<70 watts
Input Voltages	+28 VDC (Note 3) ±18 VDC + 9 VDC
Warmup Time	~24 hours to lock
Operating Temperature Range	+10°C to + 35°C (Note 4)
Size	19" rack, ~ 14" high x 24" deep
Weight	60 lbs - 80 lbs
Anticipated Life	>5 years

FIGURE 7

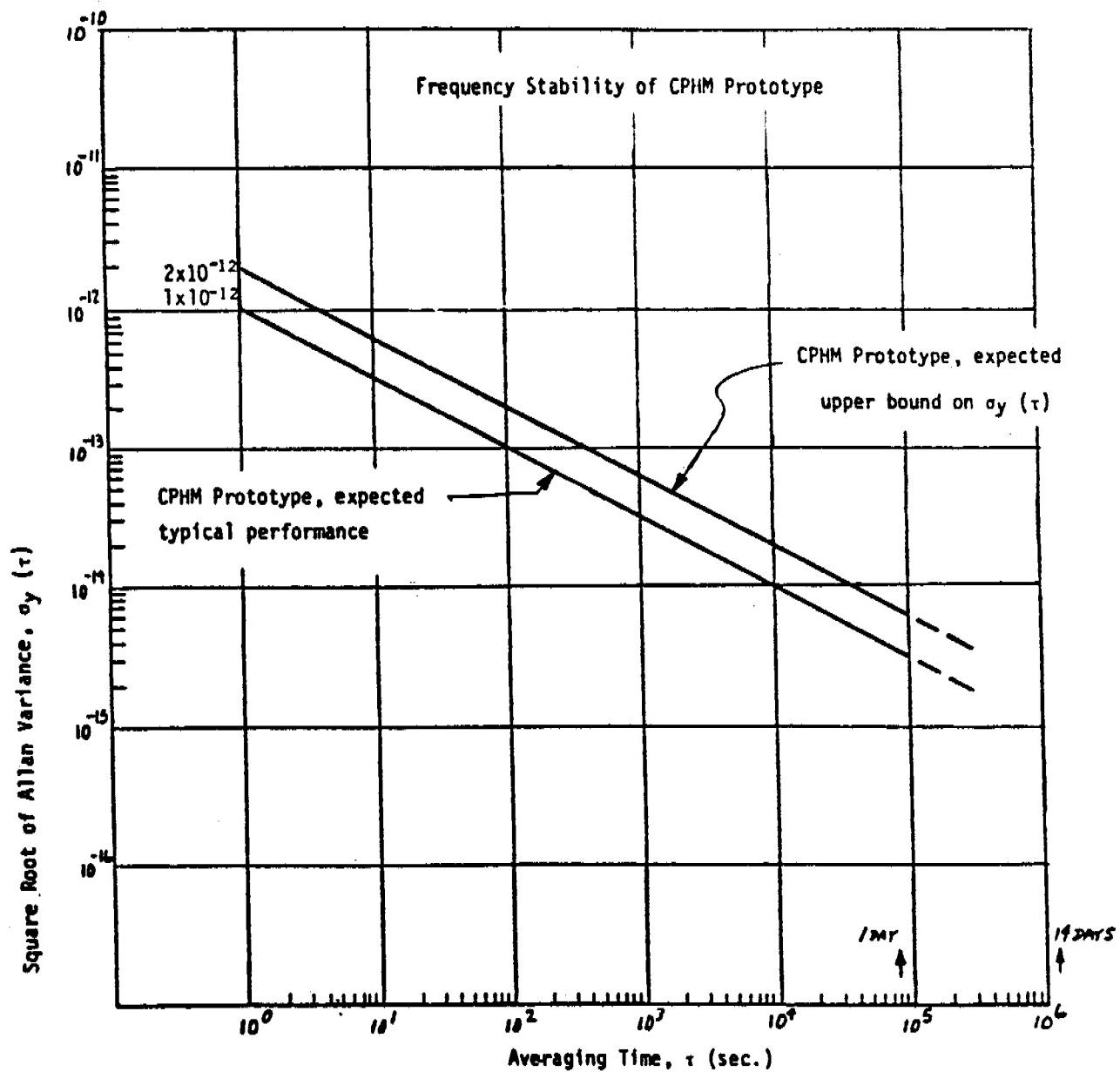


FIGURE 8

QUESTIONS AND ANSWERS

MR. SAM WARD, JPL

Have you any idea as to what is causing the drift?

MR. DIALS:

Basically, like I said, we can't find any left in this particular unit.

MR. SAM STEIN, NBS

I just wanted to say that work has been going on at NBS passive masers since about 1973, and that work was supported the whole time by the Naval Research Laboratory.

AUDIENCE:

What improvement did you find by replacing the hexapole magnet by the quadrupole magnet? Did you improve the efficiency of the source? Have you explained how that happens.

MR. DIALS:

We haven't measured that yet. That particular unit with the quadrupole; we just started looking for the hydrogen line a couple of weeks ago.

The reason we did, we expect to improve the overall size, the overall link, and secondly, we expect to improve the efficiency and we think, based on talks with Harry Peters and some other papers, that we'll buy something on the order of a factor of two to four improvement on the hydrogen line Q. But we have not measured that yet.

DR. COATES:

Thank you.